PLC/PAC/PC - based control of an electro-hydraulic servo system

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Abstract: Selection of an appropriate control system is an important decision in the process of designing an electro-hydraulic servomechanism. Nowadays, end-users have a number of options for the choice of control systems and it can sometimes be a bit confusing. The most common applied control system today are the Programmable Logic Controller (PLC), the industrial PC-based Data Acquisition (DAQ) system, and more recently the Programmable Automation Controller (PAC). In this paper, all three of these control methods will be discussed on the example of position control of electro-hydraulic servomechanisms. The experimental system consists of a main cylinder which is controlled by using a proportional directional control valve, while disturbance (i.e. reaction force) is generated by using a load cylinder with a pressure control valve.

Keywords: electro-hydraulic system, PLC, PAC, PC-based DAQ system, position control

1 Introduction

In order to achieve improved control properties, traditional electro-hydraulic systems will continue to evolve into modern systems with a significant contribution of electronics and microprocessor controlled components [1]. Modern complex hydraulic systems made up of many structural components, power equipment, control and measuring devices, programming languages, file formats and communications software need to be in harmony with each other, that the whole process is carried out without difficulty. In the increasingly complex world of microprocessor controlled automation processes, selection of a suitable control system that is fully adapted to the needs of user can be a confusing task. The most common industrial control systems today are:

- PLC (Programmable Logic Controller),
- Industrial PC-based Data Acquisition (DAQ) system,
- PAC (Programmable Automation Controller).

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The first PLCs were developed and introduced in machine automation control in early 1970s and for years they have dominated on automation markets. PLCs are designed to withstand the demands of harsh industrial environments, include multiple input/output ports to monitor process variables, usually of modular construction with improved HMI and networking capabilities to perform control applications that are sequential in nature. Some manufacturers produce motion control modules with a collection of high-level functions and functions blocks allowing the control of servo systems with more sophisticated capabilities.

Using a PLC to meet modern application requirements for network connectivity, advanced math functions, data exchange with other applications, storing large amounts of data, and large number of control loops can be a challenging task. These types of tasks are usually more suited to the capabilities of a computer (PC). Industrial PCs have become more robust control devices, designed for use in rugged environments were once only PLCs could operate. The industrial PC offers the system performance for handling all control requirements and provides additional opportunities for future functions of the control device such as condition monitoring or safety features. Due to its advantages, over the last decade, there's been an increasing trend toward the use of PC-based automation solutions.

In recent times, a relatively new acronym PAC controller is being used to describe a powerful hardware device that combines features and functionality of a PC with the reliability and ruggedness of a PLC in one efficient system. The PAC controller is suitable for the multi domain environment of modern industry and provides the advanced control methods, high-speed data acquisition and remote process monitoring, machine vision capabilities, network connectivity, expandability and interconnection with other devices.

This paper describes the construction and position control of a translational hydraulic servomechanism and the implementation of control algorithm for all three types of devices: by using a PLC controller, then by using a PC with DAQ card and finally by using a PAC controller. The article is accompanied with some typical experimental results obtained during systems testing.

2 Experimental setup description

The experimental system for translational motion control is shown in *Figure 1*. It consists of two hydraulic cylinders: a main cylinder (1), which represents the control object and a load cylinder (2), which allows setting different amount of load. Two cylinders are rigidly connected to each other by a steel joint. Both the main and the load actuator are double acting cylinders with a 50 mm bore, 36 mm diameter rods and a 300 mm stroke. The oil flow rate to the main cylinder is controlled by a proportional directional control valve (5), (Bosch-Rexroth, model 4WRA-E-6-07) with integrated electronics and ±10 V analogue input signal. The variable load is generated by using a solenoid valve (6) and a load cylinder which is able to generate a reaction force in respect of the main cylinder motion direction. This force is equivalent to the product of the piston's area and the controlled pressure which is generated by using a pressure control valve (8). The hydraulic power is provided by a hydraulic gear pump, (ViVoil, model KV-1P), with a maximum rate of 3.7 l/min and maximum nominal pressure of 25 MPa. The oil pump is driven by a single-phase electrical motor (12), 1.1 kW at 1380 rpm. The piston position of the main cylinder along its stroke is measured by using a displacement encoder (3), (Festo, type MLO-POT-300-LWG), with a resolution of 0.01 mm, which is attached to the actuator. The measured signal from the encoder is used for the realization of a control algorithm for the main servo system. Three pressure transducers (4), (Siemens, type 7MF1564), with output 0-10V, are added to measure cylinder pressures. The experimental test rig can also be used to demonstrate the working principle of conventional hydraulic system. In that case the proportional valve should be replaced with another directional control valve and a throttle valve (7) by using flexible hydraulic pipes.

In this study three control devices have been used. The first controller was a PLC controller; model SIMATIC S7-1200, manufactured by Siemens. The program has been built with the ladder logic diagram using SIMATIC WinCC flexible software for programming controller and configuring HMI panel. Then, a PAC controller, model CompactRIO-9014, manufactured by National Instruments. The control program has been developed using LabVIEW graphical language. Finally, a PC-based system, by using a NI DAQCard-6024E (for PCMCIA), which offers both 12-bit analogue input and analogue output. The control algorithm has been developed in the Matlab/Simulink environment supported by Real-Time Workshop (RTW) program for generating the C code and building a real-time application.

The considered system is actually one of three experimental electro-hydraulic systems at our Laboratory that have been made for research purposes in the field of hydraulic systems control, as well as for training students [2, 3]. The other two test systems are: the module for force control and the module for rotational motion control. These modules have the characteristics of general electro-hydraulic systems that can be found in commonly used industrial settings.

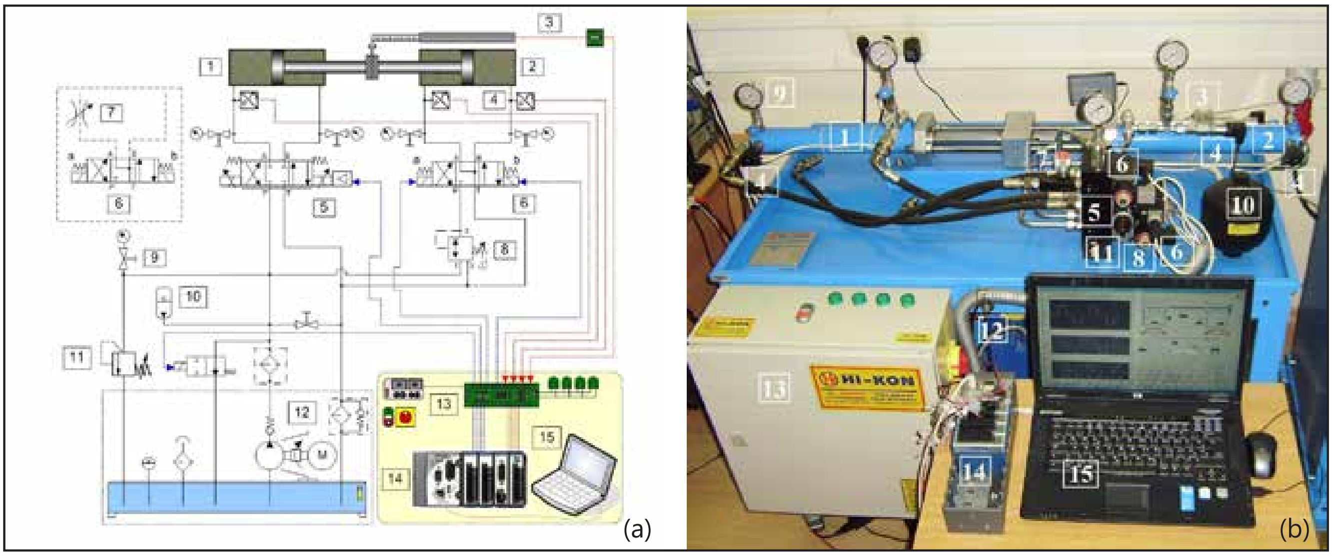

Figure 1. *Module for translational motion control, a) schematic diagram, b) photo*

1–Main cylinder, 2–Load cylinder, 3–Linear encoder, 4–Pressure sensor, 5–Proportional control valve, 6–Solenoid valve, 7–Throttling valve, 8–Pressure control valve, 9–Manometer, 10–Hydraulic accumulator, 11–System pressure relief valve, 12–Electric motor, 13–Electronic interface, 14–CompactRIO controller, 15–Control computer

3 Model of the control system

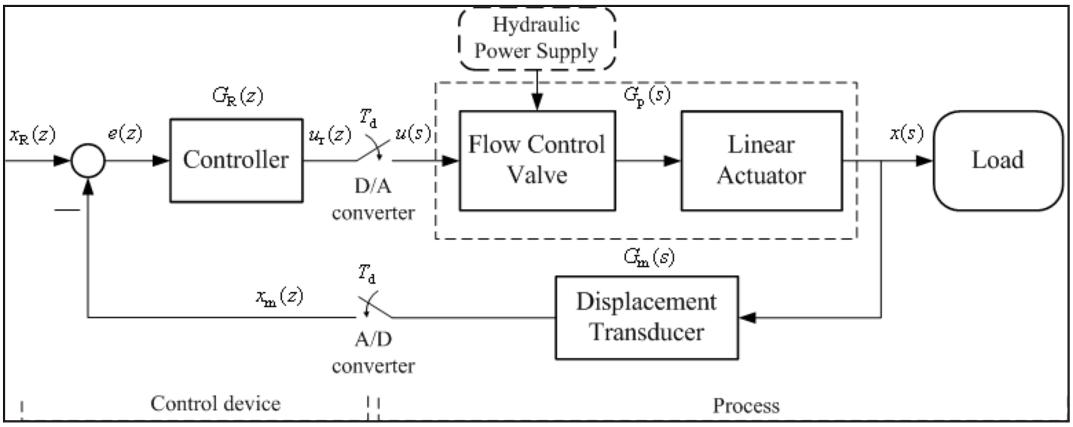

Figure 2. *Principal block scheme of hydraulic position control system*

A dynamic model of an electro-hydraulic system is nonlinear and can be derived by analyzing the proportional valve dynamics, then by applying the flow continuity through the valve orifice, by analyzing the pressure behaviour in the cylinder chambers, and finally by applying the force balance equation for the cylinder. Such nonlinear model can be used to simulate the dynamic behaviour of the system and to apply advanced control system techniques [4]. However, for the classical feedback controller synthesis, a linearized control-oriented model is needed, which can still represent the real system behaviour, *Figure 2*.

The transfer function *G*(*s*) that relates the position of the actuator *x* and the valve control signal *u* can be expressed as follows [5]:

$$G(s)=\frac{x(s)}{u(s)}=\frac{k_v\,\omega_v^2\,K_q/A_p}{s\,(s^2+2\zeta_v\,\omega_v+\omega_v^2)\left[\dfrac{V_t\,M_t}{4B\,A_p^2}s^2+\left(\dfrac{K_{ce}\,M_t}{A_p^2}+\dfrac{b\,V_t}{4B\,A_p^2}\right)s+1\right]} \qquad (1)$$

The parameters of the experimental test system for controller design are summarized in *Table 1*. In this structure only the measurement of the cylinder position is necessary for the implementation of the control algorithm.

Table 1. *Values of the system parameters*

System parameters	Value
Valve spool position gain	$k_v=5.5\cdot10^{-6}$ m/V
Valve natural frequency	$\omega_v=113$ rad/s
Valve damping ratio	$\zeta_v=0.4$
Valve flow gain	$K_q=1.433$ m^2/s
Piston annulus area	$A_p=14.54\cdot10^{-4}$ m^2
Cylinder volume	$V_t=0.654\cdot10^{-3}$ m^3
Load mass	$M_t=580$ kg
Effective bulk modulus	$B=1350\cdot10^{6}$ Pa
Total flow-pressure coef.	$K_{ce}=6\cdot10^{-11}\ m^3/Pa\ s$
Viscous damping coef.	$b=455$ Ns/m
Measuring system gain	$K_m=33.33$ V/m

4 Experimental results

- ***PLC controller***

The experimental results for the position control of the hydraulic cylinder realized by using the PLC *Simatic* S7-1200 is shown in Figure 3. The control program has been built using *WinCC flexible* software for programming the controller and configuring the HMI (human machine interface) panel. Using the HMI is intuitive, with a graphic and textual screen display, trend and alarm display and it can perform real-time control and monitoring of the process. The reference value can be directly changed, and there is a graphic representation of the measured values over time. Below the graphic display of the process condition there is also an alarm table, which gives the operator some important states in the control process. The PID function block uses the following formula to calculate the output value [6]:

$$y=K_P\left[(b\cdot w-x)+\frac{1}{T_I\cdot s}(w-x)+\frac{T_D\cdot s}{a\cdot T_D\cdot s+1}(c\cdot w-x)\right] \qquad (2)$$

where:

y – output value	K_P – proportional gain	a – derivative delay coefficient
x – process value	T_I – integral time constant	b – proportional action weighting
w – setpoint value	T_D – derivative time constant	c – derivative action weighting

- ***PC-based DAQ system***

The experimental results for the position control of the hydraulic

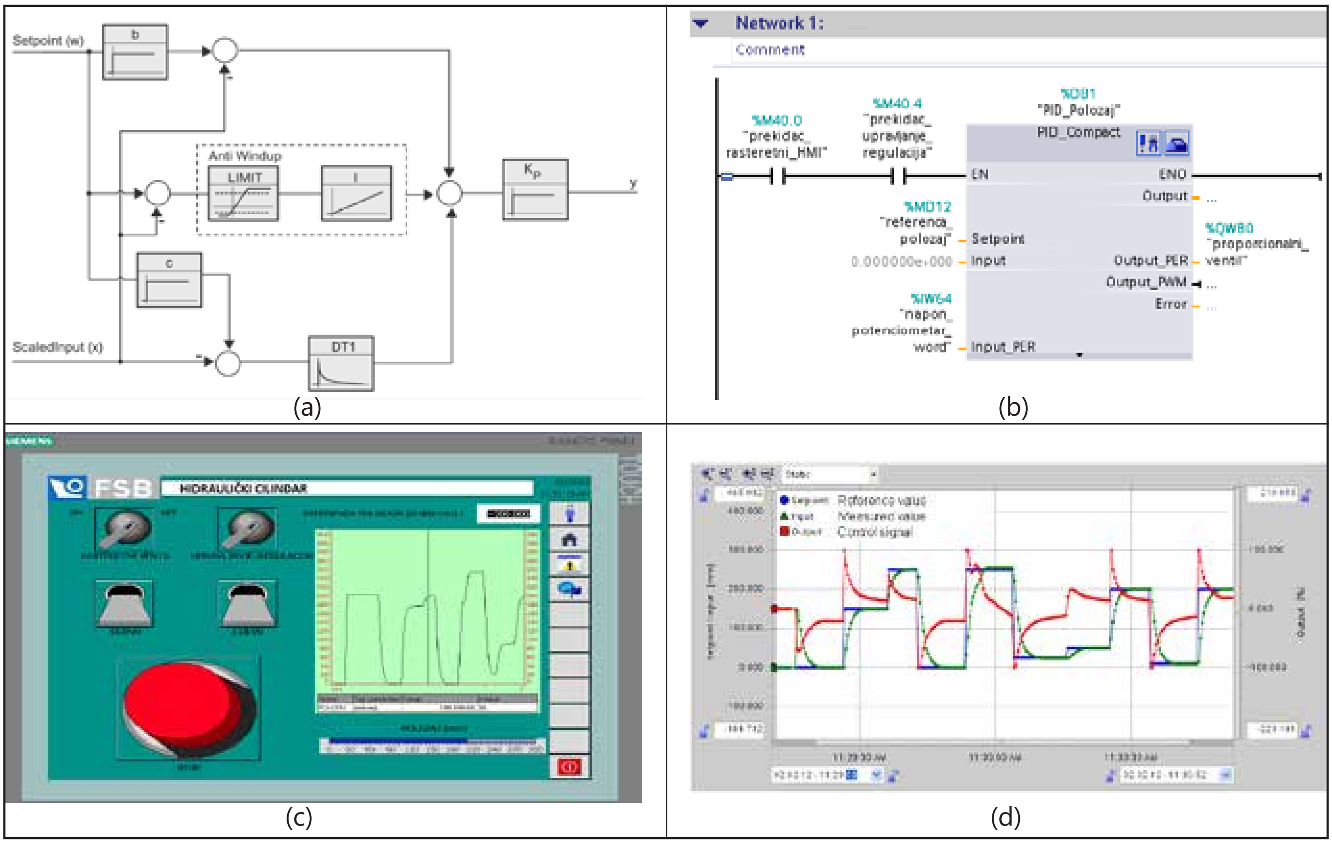

Figure 3. *Position control of the hydraulic cylinder realized by using the PLC: a) Structure of the PID controller, b) PID function block with self-tuning mode, c) Realized HMI interface, d) Experimental results*

cylinder realized by using a laptop PC with DAQ card is shown in *Figure 4*. The control algorithm is realized in widely used Matlab/Simulink program and the Real-Time Workshop (RTW) platform, which allow using a familiar GUI (graphical user interface) to perform real-time control of the system [7]. The control algorithm is handled by a computer card NI DAQCard-6024E (for PCMCIA), which offers both 12-bit analogue input and analogue output. This control solution allows design changes to be made directly to the block diagram, continuous monitoring, data acquisition and real-time control of the process. The command voltage to the proportional valve is generated by analogue output and to the solenoid valves by digital outputs on the DAQ board.

- ***PAC controller***

The experimental results for the position control of the hydraulic cylinder using the PAC controller (NI CompactRIO-9014) are shown in *Figure 5*, both for unloaded drive and for the case when the load was activated after 25 s. The control algorithm is realized in LabVIEW environment, which uses a graphical language (G), to create programs in block diagram form. LabVIEW includes libraries of functions and development tools designed specifically for data acquisition and control, data analysis, and data presentation [8]. In order to better monitoring the main parameters of the system, the graphics are installed on the front panel for visualization of the process. CompactRIO controller has an industrial processor that reliably and deterministically executes LabVIEW real-time application and enables the high performance and communication with peripheral devices.

5 Conclusion

In the initial design process of an electro-hydraulic servomechanism very often stands the selection of an appropriate control device. Choosing the most effective controller for a particular application depends on a number of factors like:

- compatibility of new devices with existing equipment,
- harmful environmental impact on the controller's operation,
- whether the controller supports I/O requirements and needed signal types,
- requirements for special features of the controller hardware,
- requirements for both local and remote process control,
- communications capability and protocols that allows selected controller,
- programmability and requirements for advanced functions and data manipulation, etc.

In this paper the most common used control devices today like PLC controller, PC-based DAQ system and PAC controller have been implemented on an electro-hydraulic servomechanism for translational positioning. The article is supported by the most basic ways of programming these devices, possible ways of presenting the results to the user and some typical experimental re-

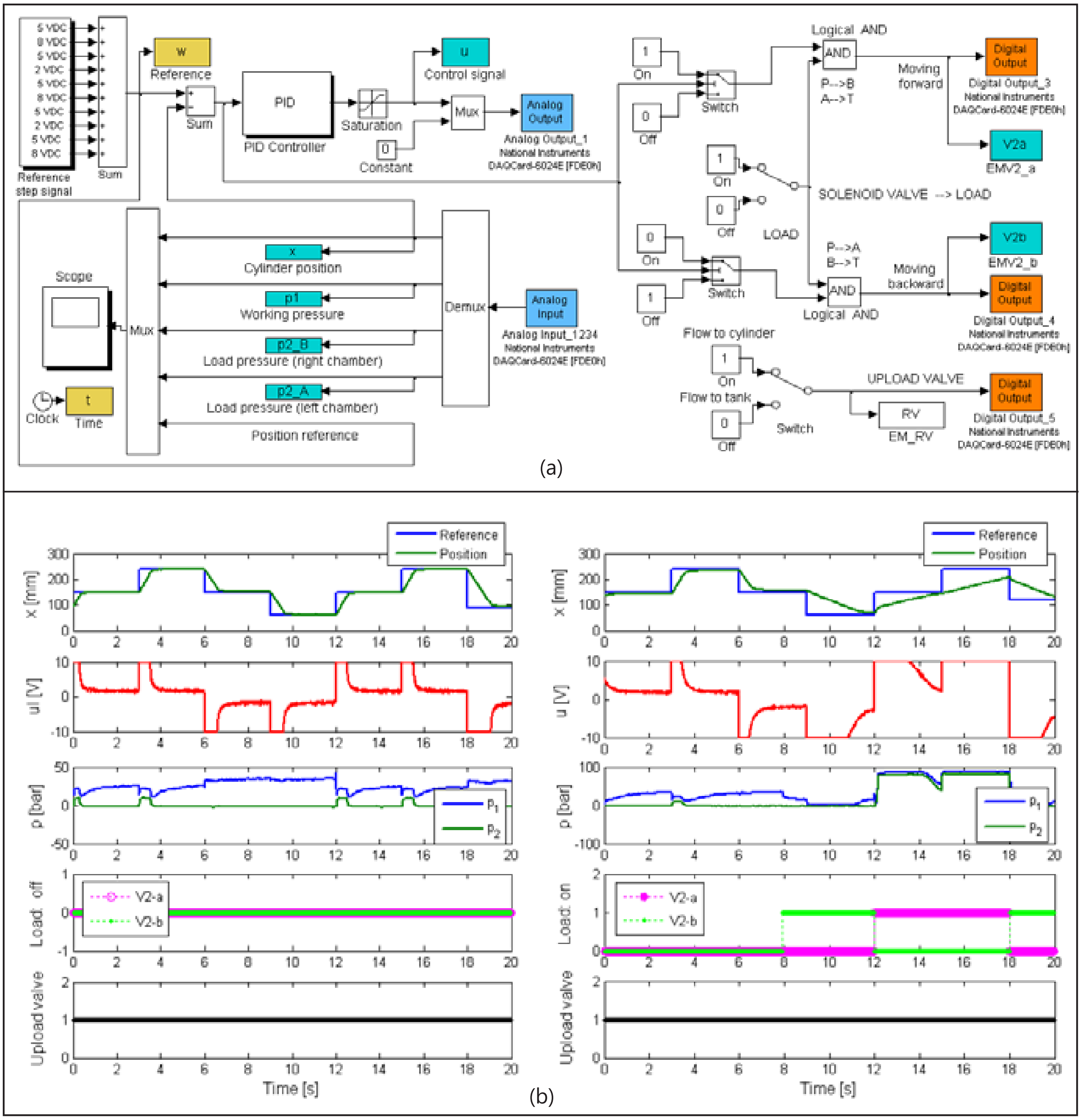

Figure 4. *Position control of the hydraulic cylinder realized by using the PC-based DAQ system: a) Simulink/RTW model, b) Experimental results, left: without load, right: with load*

sults obtained during the system testing.

For less demanding applications, PLC device as a fundamental control element in rugged industrial environments is often satisfactory and their use will be continued in the future. Nowadays, PLCs have also started to add new features that have allowed PCs and now offer higher performance, ethernet communications capability and sophisticated self-diagnostic tools. However, PC-based DAQ system and PAC controller provides various control functions and other reliability features that are required in today's modern industry but certainly at a higher price.

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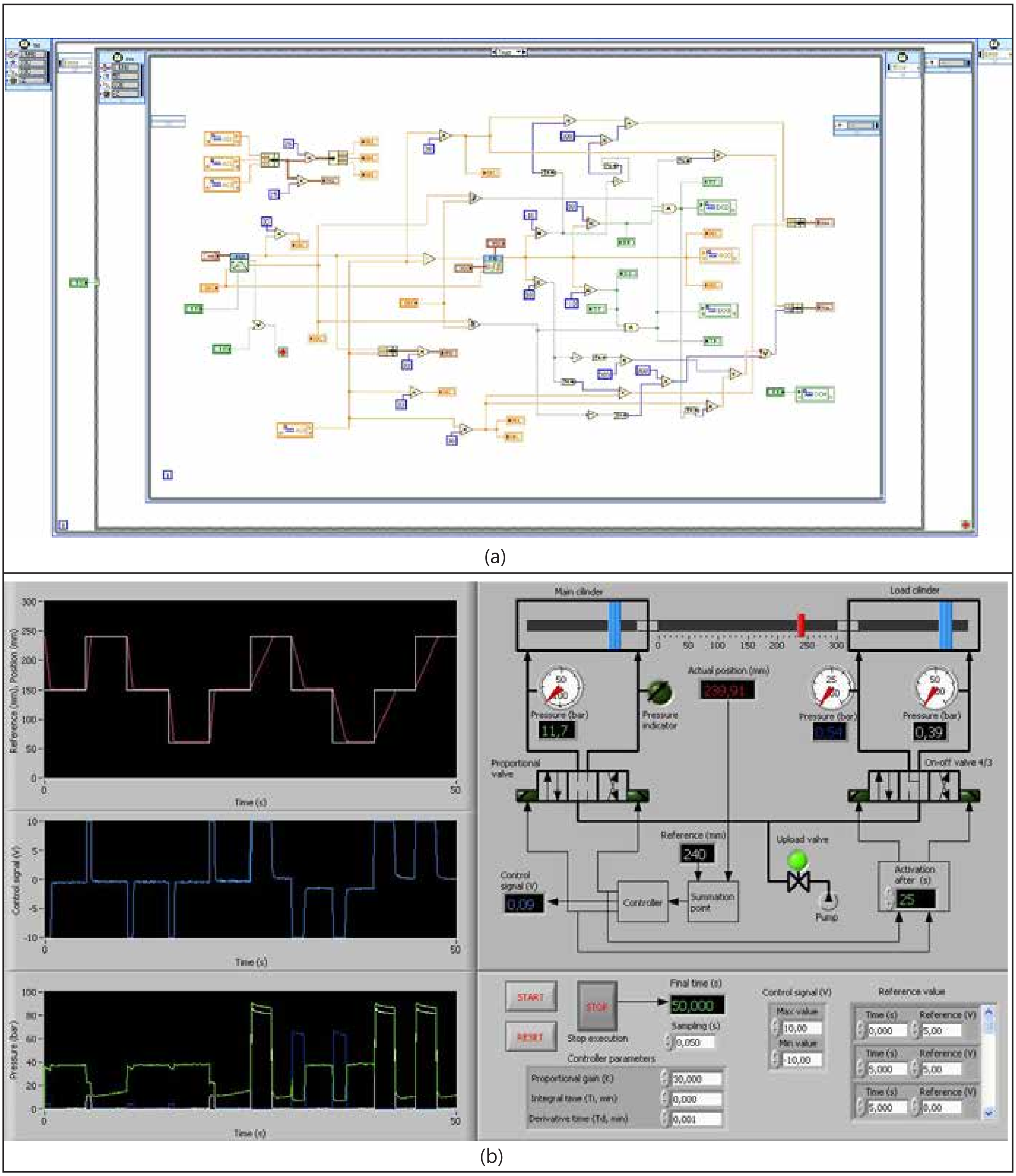

Figure 5. *Position control of the hydraulic cylinder realized by using the cRIO controller: a) Block-diagram in graphical program LabVIEW, b) Experimental results – HMI based on LabVIEW*

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PLC/PAC/PC – krmiljenje zvezno delujočega elektrohidravličnega sistema

Razširjeni povzetek

Izbira primernega krmilnega sistema ima pomembno vlogo v procesu projektiranja novega elektrohidravličnega pogona. Dandanes imajo končni uporabniki veliko možnosti izbire med različnimi krmilnimi sistemi, kar pa lahko povzroča zmedo. Danes najbolj uporabljani krmilni sistemi so programabilni logični krmilnik (PLC), industrijski računalnik (PC-DAQ) in programabilni samodejni krmilnik (PAC). V prispevku so prikazane vse tri možnosti krmiljenja na primeru regulacije pozicije elektrohidravličnega zvezno delujočega linearnega pogona. Eksperimentalni sistem vsebuje glavni hidravlični valj, krmiljen z uporabo proporcionalnega potnega ventila, in obremenitveni hidravlični valj, preko katerega se ustvarja reakcijska sila s pomočjo tlačnega ventila.

Slika 1 prikazuje funkcijsko shemo in fotografijo hidravličnega preizkuševališča, na katerem so bili preizkušeni trije različni krmilni sistemi.

Slika 2 predstavlja osnovni blokovni diagram za hidravlično regulacijo pozicije bremena.

Slika 3 prikazuje način regulacije pozicije z uporabo programabilnega logičnega krmilnika (PLC) in rezultat meritev.

Slika 4 prikazuje način regulacije pozicije z uporabo računalnika (PC-DAQ) in rezultat meritev.

Slika 5 prikazuje način regulacije pozicije z uporabo programabilnega samodejnega krmilnika (PAC) in rezultat meritev.

Programabilni logični krmilnik (PLC) je primeren za manj zahtevne aplikacije kot osnovni krmilni element za groba industrijska okolja. Sodobni PLC-krmilniki omogočajo povezavo z osebnimi računalniki, komunikacijo Ethernet in samodiagnostična orodja. Vse to močno povečuje njihovo zmogljivost, uporabnost in dostopnost. Krmilna sistema PC-DAQ in PAC pa omogočata številne krmilno-nadzorne funkcije in druga orodja, ki so danes potrebna v moderni industriji, seveda za višjo ceno.

Ključne besede: elektrohidravlični sistem, krmilnik, PLC, PC-DAQ, PAC, regulacija pozicije

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